DTT magnet system

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on behalf of DTT team

ILO Industrial Opportunities Days

07/06/2019

Istituto Nazionale di Astrofisica - Capodimonte (Napoli)

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Outline

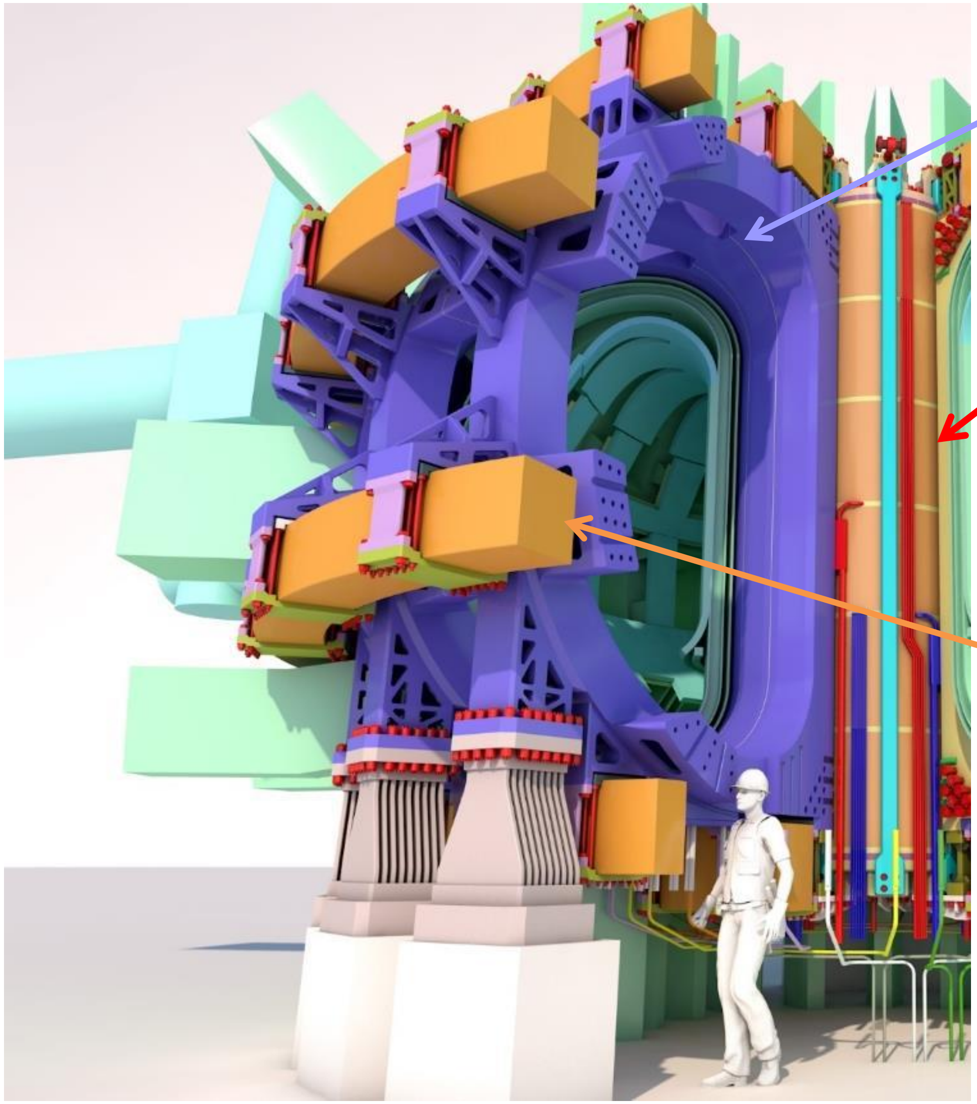
- DTT magnet system overview
- Main procurements:
  - Superconducting and Copper strands
  - Coils conductors
  - Toroidal Field Coils
    - Winding pack
    - Casing
    - Integration
    - Testing
  - Central solenoid coil
  - Poloidal Field coils

DTT magnet system at a glance

Design requirements & constraints:

- Flexibility for plasma shaping
- 6 T on plasma @ 2.14 m radius
- Ripple < 0.5%
- Pulse length ~ 100 s
- Mature technology for schedule & budget constraints

Magnet system: overview



18 Toroidal Field coils
Nb_3Sn Cable-In-Conduit Conductors
5 *Double-Pancakes* (3 regular + 2 side)

6 Central Solenoid module coils
Nb_3Sn Cable-In-Conduit Conductors
6 *independent modules*

6 Poloidal Field coils
4 NbTi Cable-In-Conduit Conductors
2 Nb_3Sn Cable-In-Conduit Conductors
6 *independent modules*

Design based on proven and reliable technologies

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Superconducting & Copper Strands procurement

- ✓ Market survey notice issued on 21/12/2018 (https://enea.ubuy.cineca.it/)

To set-up a list of qualified economic operators to be invited to a procedure

- ✓ Deadline for submission expression of interest on 22/01/2019

- ✓ Tender procedure (through negotiated procedure): invitation sent on 29/04/2019

Most economically advantageous tender (MEAT) criterion adopted

- ✓ Deadline for presentation of offers: 27/05/2019

- ✓ Start of evaluations: 29/05/2019

- ➢ Completion of procedure and contract award expected within summer

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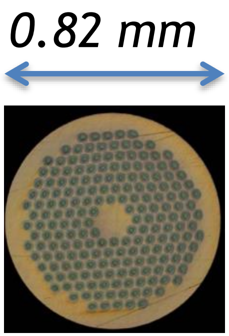
Superconducting & Copper Strands procurement

The procurement has been divided in 4 lots:



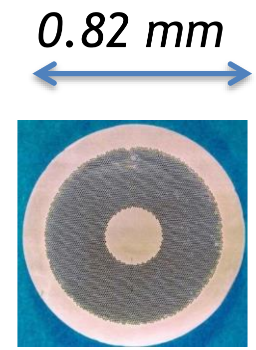
1. Nb_3Sn (chromium coated) for TF:
Hi-Grade performance at 4.2K: Ic (4.2K, 12T, 0.0% applied strain(*)) > **285 A**
hysteresis losses < 1000 mJ/cm^3
L = 900 + n*900
55 tons for TFC
< 38 weeks for first 3 tons form KoM

2. Nb_3Sn (chromium coated) for CS & PF1/6:
Hi-Grade performance at 4.2K: Ic (4.2K, 12T, 0.0% applied strain(*)) > **260 A**
hysteresis losses nts < 400 mJ/cm^3
L = 1050 + n*530
22 tons for CS & PF1/6
< 35 weeks for first 2 tons from KoM

* ITER barrel measurement

Superconducting & Copper Strands procurement

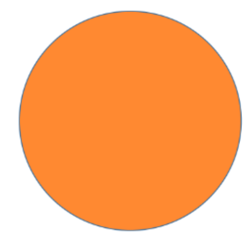
The procurement has been divided in 4 lots:



3. NbTi (nichel coated) for PF2/3/4/5:

Required Performance at 4.2K: Ic (4.2K, 5T) ≥ **500 A**
hysteresis losses < 100 mJ/cm^3
L = 5000 + n*10000
27.5 tons FOR PF2/3/4/5
< 42 weeks for first 6 tons from KoM

4. Cu (chromium coated) for TF, CS & PF1/6 and (nichel coated) for PF2/3/4/5:



0.82 ± 0.005 mm, Cr/Ni coating = 2 ± 1 μm
L = 5000 + n*10000
RRR: > 300
31 tons FOR TFC & CS & PF1/6 + 23 tons FOR PF
< 26 weeks for first 7 tons from KoM

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Coils Conductors procurement

Conductors manufacturing will consist in:

- Cabling
- Jacketing & insertion
- Spooling
- Testing
- Shipping to coil manufacturers
- Tender launch in 08/19

Key issues:

- 316 LN jacket (samples and dummies to be provided in advance for winding test)
- 100% welds testing
- He leak testing (pressure, flow)
- Jacketing line ~ 880 m (for CS & PF)

- TF - ULs:
  54 rDP + 36 sDP + 8 spare
- PF - ULs:
  18 DP-PF1/6 + 1spare + 16 DP-PF2/5 + 1 spare + 14 DP-PF3/4 + 1 spare
- CS - ULs:
  6 HF + 1 spare + 12 LF + 2 spare

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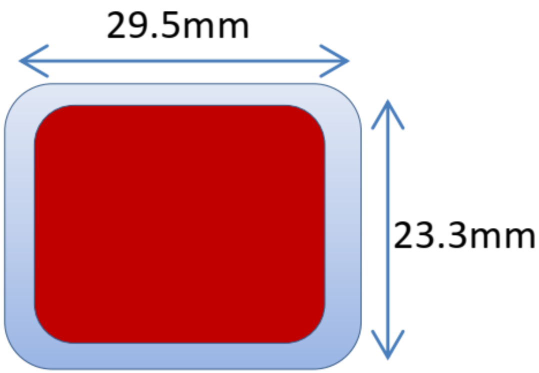
TF coils Conductors

TF Conductors manufacturing schedule:

- Cu dummies to be available 03/20
- First set of UL (including 1 superdummy) 06/20
- Production rate: 1 set/40 work. days



Main features:

- Unit length (UL): 240 m (regular), 170 m (lateral)
- Total # of ULs: 54 (regular) + 36 (lateral) + 8 spare
- Inner corner radius: 3.5mm
- VF: 26.4%
- Nb3Sn strands: 504
- Cu segregated strands: 144
- Cabling pattern:
  [(1Cu+2Nb3Sn)+(1Cu+2Nb3Sn)+3Nb3Sn]*3*4*6
  Wrapping: 0.05mm thick, overlap 30%

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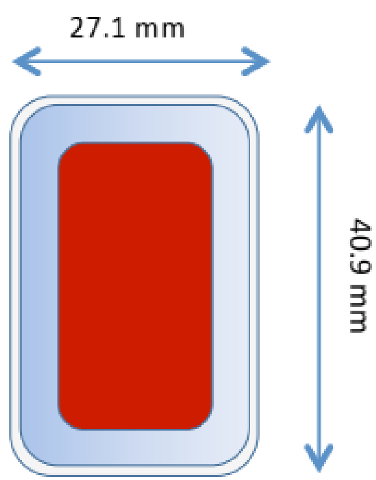
CS coils conductors

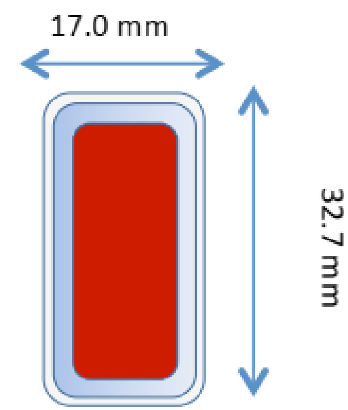
	CS- HF	CS- LF
Operating current (kA)	29.04	29.04
Superc. Strands (0.82 mm)	648	180
Area no_Cu (mm2)	171.1	47.5
Cu strands (0.82 mm)	0	204
Area TOT. Cu (mm2)	171.1	155.2
Cable pattern	3 x 3 x3 x4 x 6	(2s.c.+1Cu)x3x(5+C1)x(6+C2); C1=3x3; C2=3x4x5
V.F. (%)	27	26
Jacket Thickness (mm)	4.1	2.0
Inner corner radius (mm)	4.1	2.0

CS - ULs:

6 HF + 1 spare

12 LF + 2 spare





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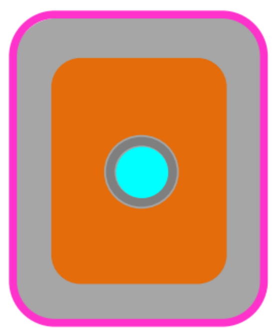
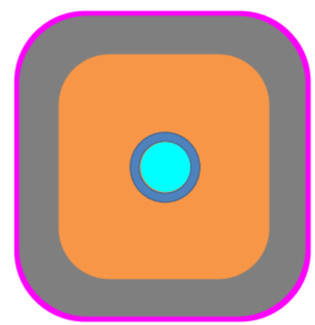
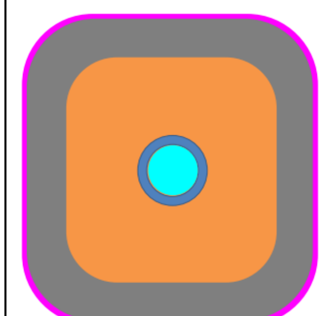
PF coils conductors

Conductor	PF1/6	PF2/5	PF3/4
Radial Ext. Dim. (mm)	23.4	26.4	26.4
Vertical Ext. Dim. (mm)	28.2	27.7	27.7
Jacket thickness (mm)	3.0	3.0	3.0
Inner Corner Radius (mm)	3.5	3.5	3.5
Central Channel (OD/ID; mm)	7/5	7/5	7/5
Inter-turn insulation (mm)	1.8	1.8	1.8
# SC strands (0.82mm, 1.9 Cu/noCu)	180 (Nb_3Sn)	162 (NbTi)	324 (NbTi)
# Cu strands (0.82mm, 1.9 Cu/noCu)	216	324	162
Total strand number	396	486	486
Void fraction	29.9%	31.9%	31.9%
Cable overlapping	0.1mm, 50%, SS		
PF - ULs: 18 DP-PF1/6 + 1spare 16 DP-PF2/5 + 1 spare 14 DP-PF3/4 + 1 spare			

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TF coils overview

18 Toroidal Field coils

Nb_3Sn Cable-In-Conduit Conductors

5 *Double-Pancakes* (3 regular + 2 side)

Double-Pancake winding 80 turns

Max. hydraulic length: 110 m

I_{op}: 44 kA

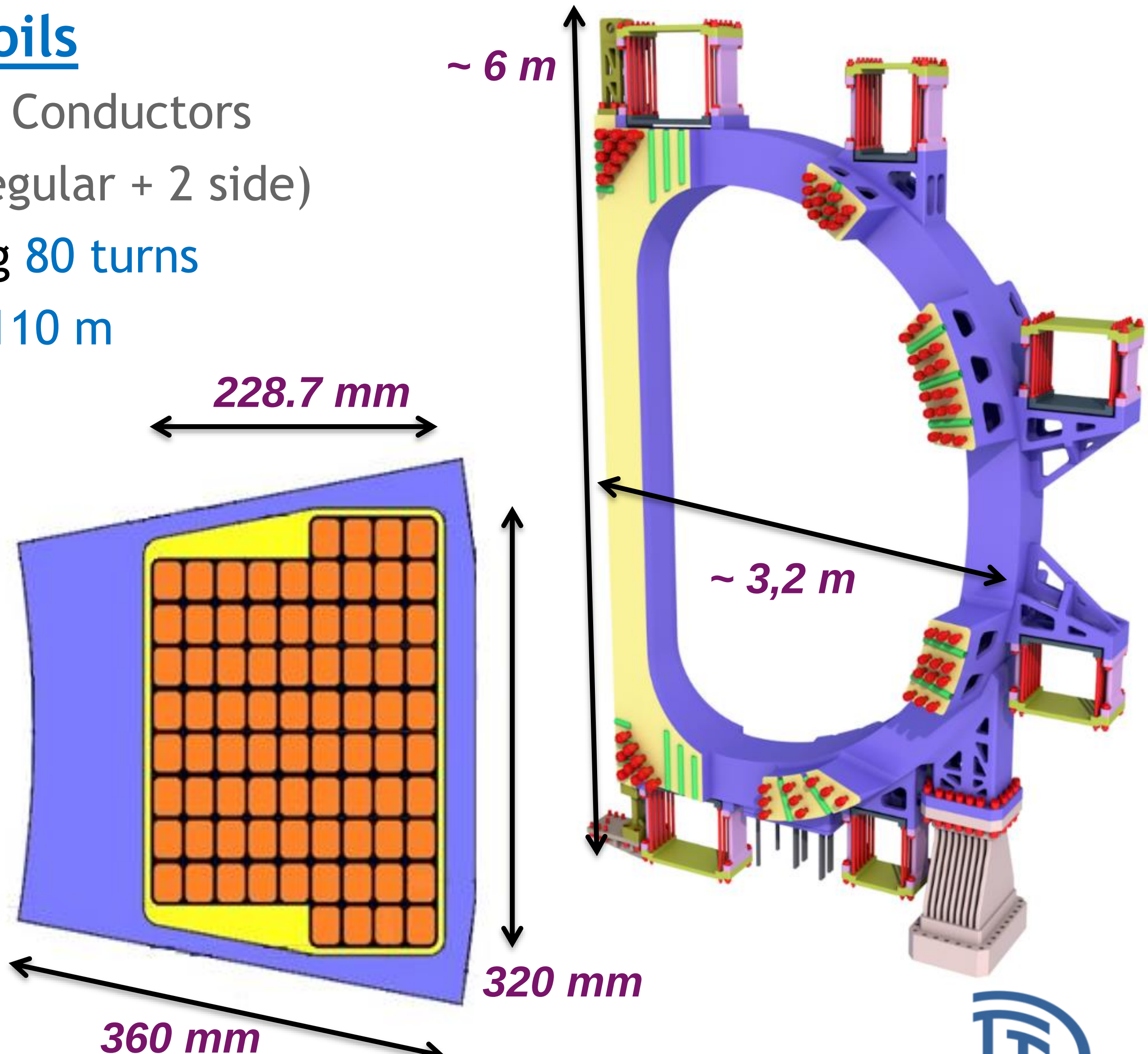
B_{max}: 11.8 T

ΔT_{margin} > 1.5 K

Mass 15 tons

Jacket &Case material

316LN



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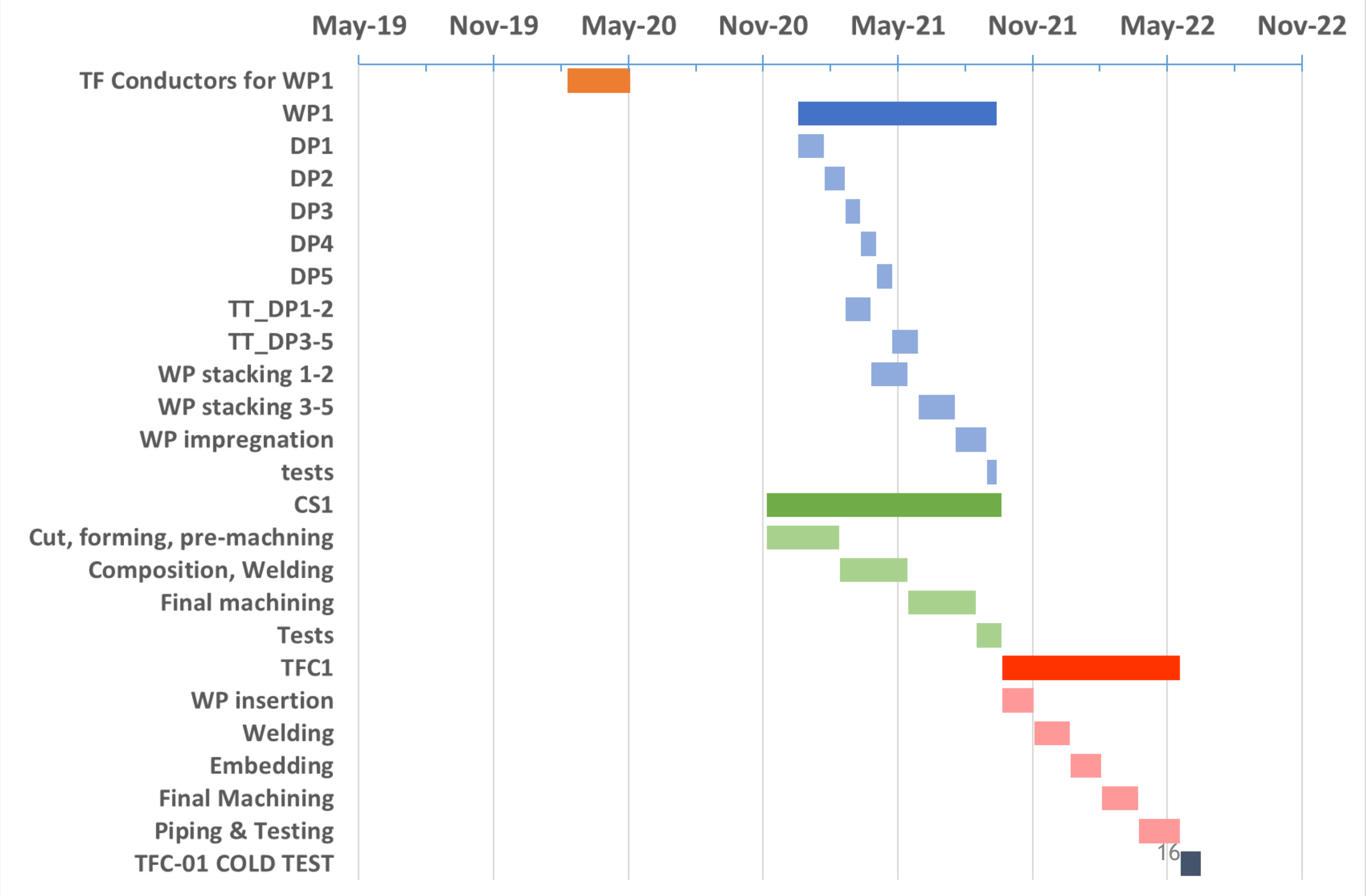
Manufacturing planning: TFC-01 (an example)



TF coils: qualification activities for WP

- Heat treatment (up to 650°C for ~ 2 weeks < 200 ppm O2 and other impurities)
- Insulation after heat treatment
- Internal joint (<2nOhm) to be tested in cryogenic conditions
- Vacuum pressure impregnation (VPI) ->
- Shear strenght test of insulation
- High voltage DC tests in vacuum (Paschen proof) -> Vacuum chamber

~ 0.7 m of vertical displacement allowed (ε<0.1%)

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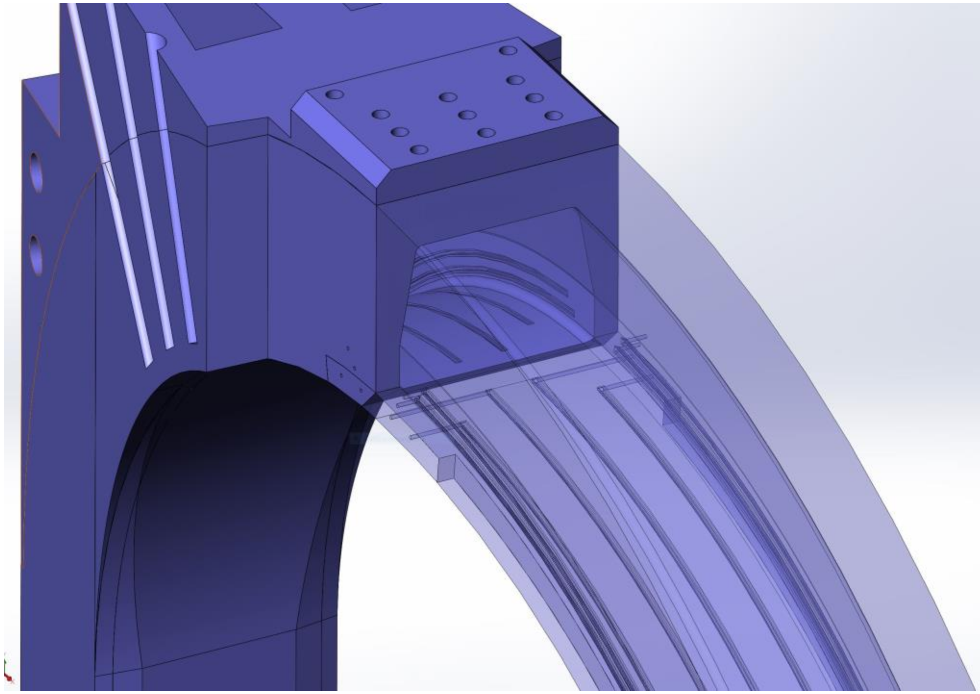
TF coils: casing

TF casing manufacturing schedule:

- First delivery: 10/21
- Production rate: ~1 casing/months



~ 10 tons

Max thickness: ~ 90 mm

Support structures for PF included

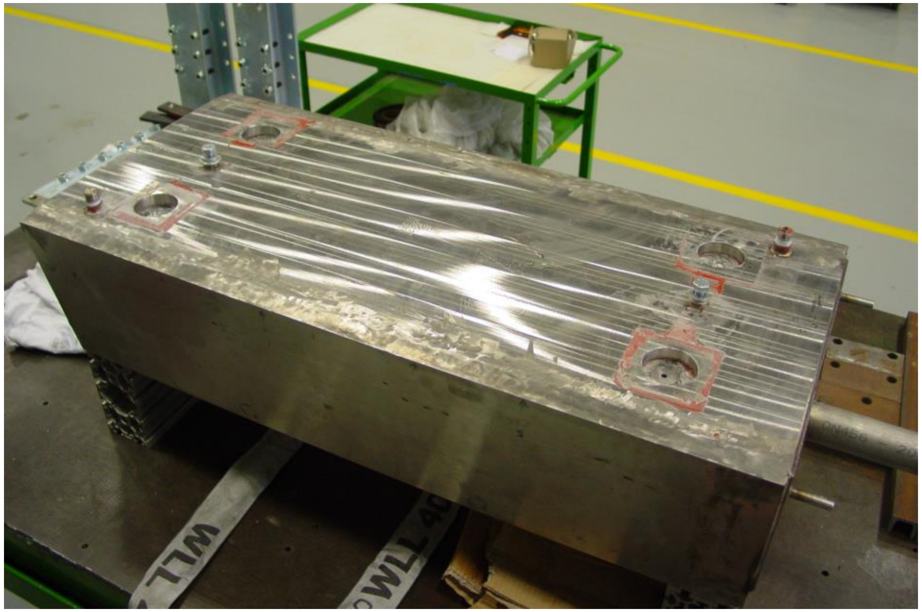
Outer Intercoil structures included

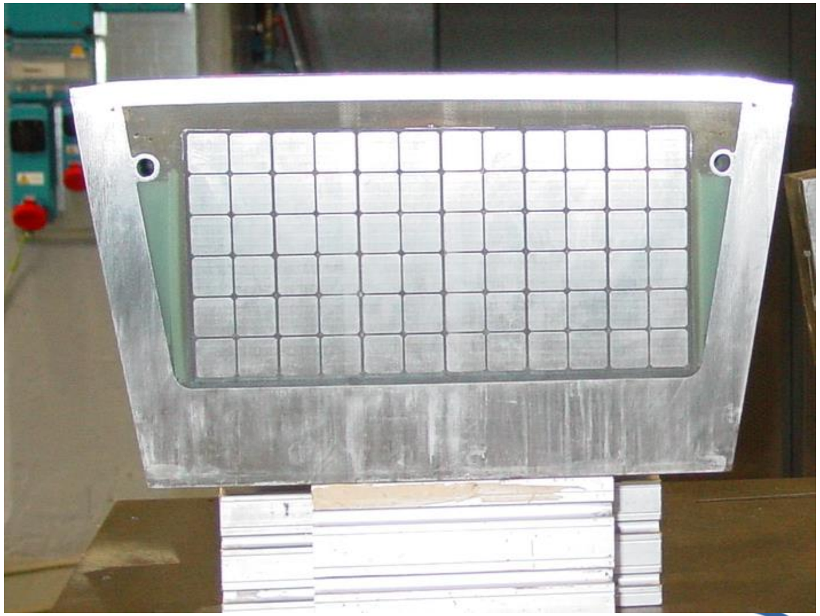
Key issues:

- 316LN
- 100% welds control
- Dimensional controls with laser track
- Channels for cooling machined inside and sealed
- Jigs for composition and trasnport
- Mock-ups availability for coil integration in 09/20

TF coils: qualification activities for TF integration

- Welding process qualification record -> chamfer design
- WP insertion and embedding qualification
- Machining qualification and measurement (general medium tolerance class specified unless otherwise stated)
- Piping layout and welding process
- High voltage DC tests in vacuum (Paschen proof) for piping





Courtesy of JT-60SA

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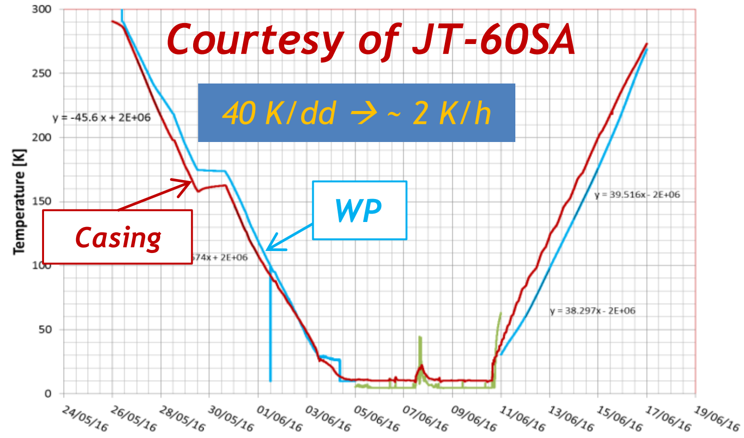
TF coils: testing

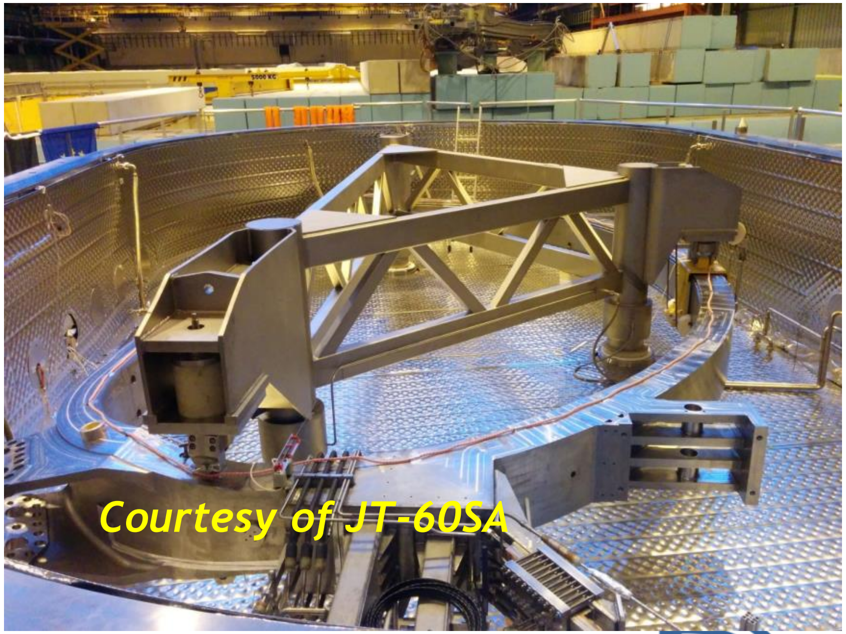
TF cryogenic testing in ENEA:

- Commissioning 10/21
- First TF test in 06/22
- Test rate: ~ 2 month per TFC including coil preparation, cool-down (1 week), testing (1 week), warm-up, coil release



Key issues:

- High voltage DC tests in vacuum at Cryogenic
- 4,5 K, 6 bar, nominal current
- Quench test
- Insulation resistance test
- Joint resistance test (< 2 nOhm)



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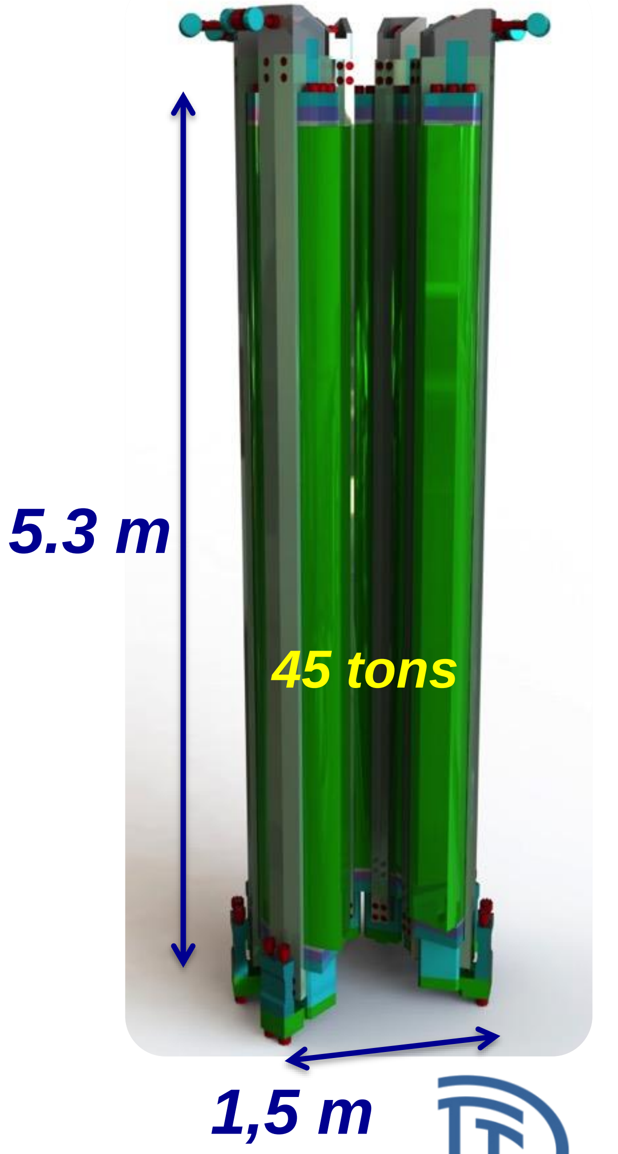
CS coil overview

Requirements

- 6 independently fed modules;
- flux swing > 32.4 Weber;
- Rmax < 824 mm innermost TF radius;
- Allow the future implementation of an additional insert coil (made of HTS)

Design choices *(in current design_v22)*:

- Nb_3Sn Cable-In-Conduit Conductors
- **CICC I_{op}:** 29.04 kA;
- **B_{peak}:** 13.2 T
- **Rmin / Rmax:** 443 mm / 755 mm
- **Turns per module:** 120 (HF) + 200 (LF)
- **DT_{margin} >** 1.0 K



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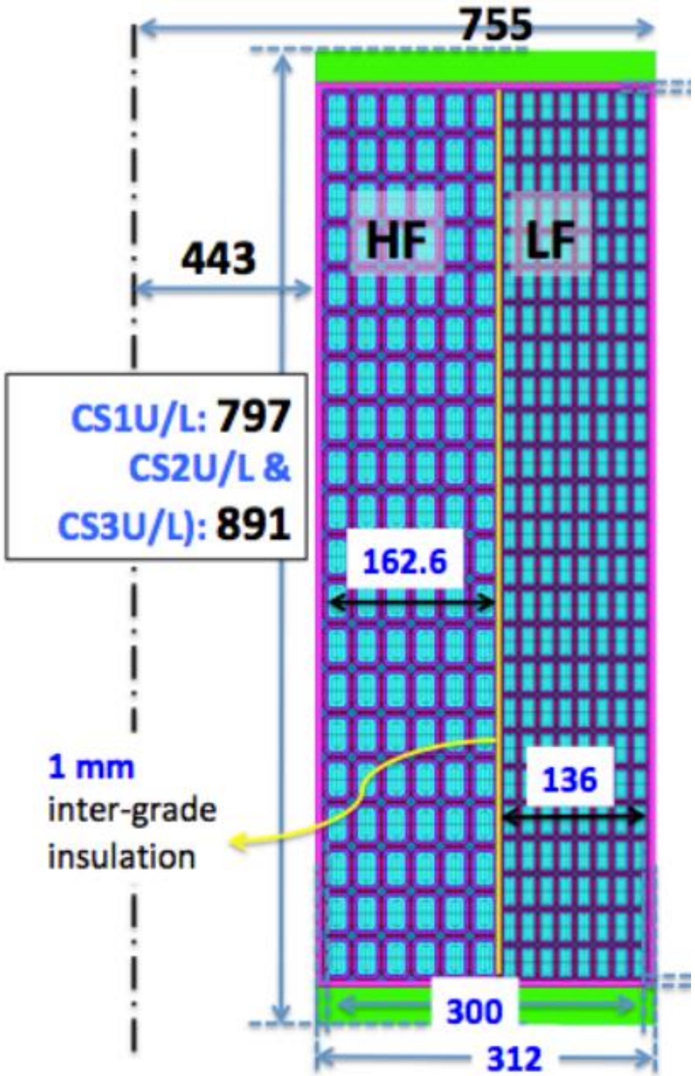
CS coils: CS modules

CS module manufacturing schedule:

- First delivery (CS-00 for Cold test): 12/21
- Production rate: ~6 months/module

Coil height		~ 0,9 m
Coil inner diameter		~ 0,9 m
Coil outer diameter		~ 1,5 m
Mass		~ 7 tons
Turns HF	6 x 20	
Turns LF	8 x 25	

Cycling loading conditions (> 25000 cycles)

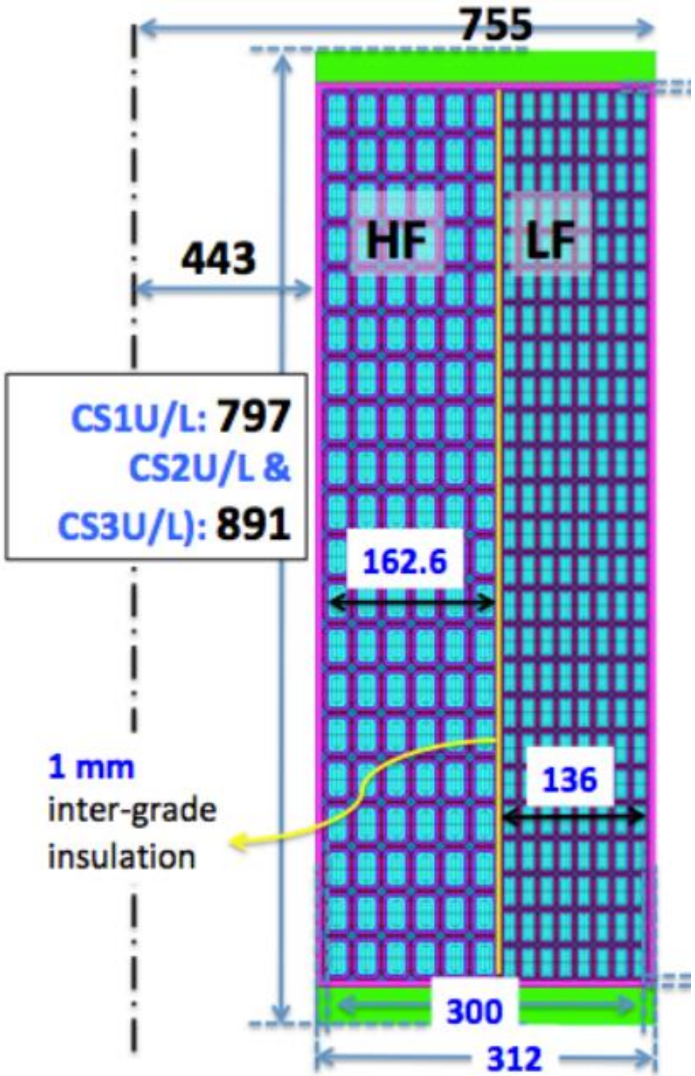


All dimensions at 4 K

CS coils: CS modules

Key issues:

- **Layer wound solution with conductor grading (2 grades)**
- Insulation before heat treatment (only glass)
- Embedded joints bewteen layers
- Vacuum pressure impregnation
- High voltage DC tests in vacuum (Paschen proof)
- Tight tolerance on current line diameter and center axis
- Assembly to be performed after testing of each module in cryogenic conditions and full current



All dimensions at 4 K

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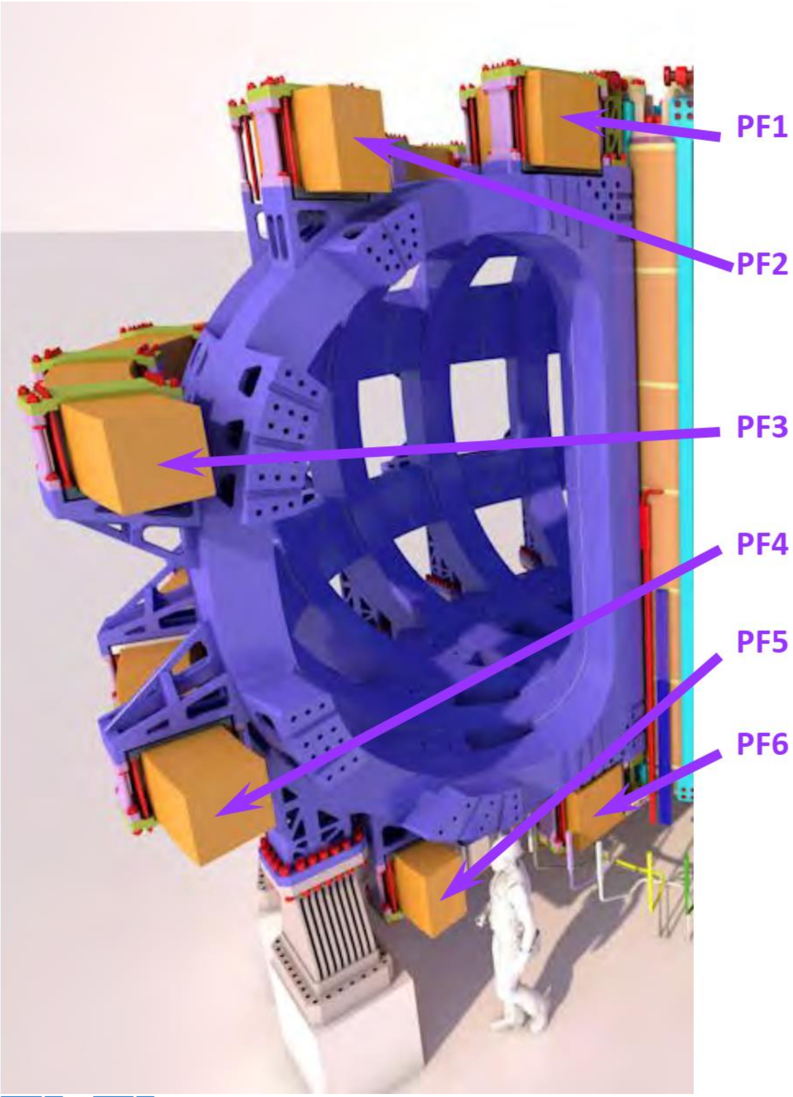
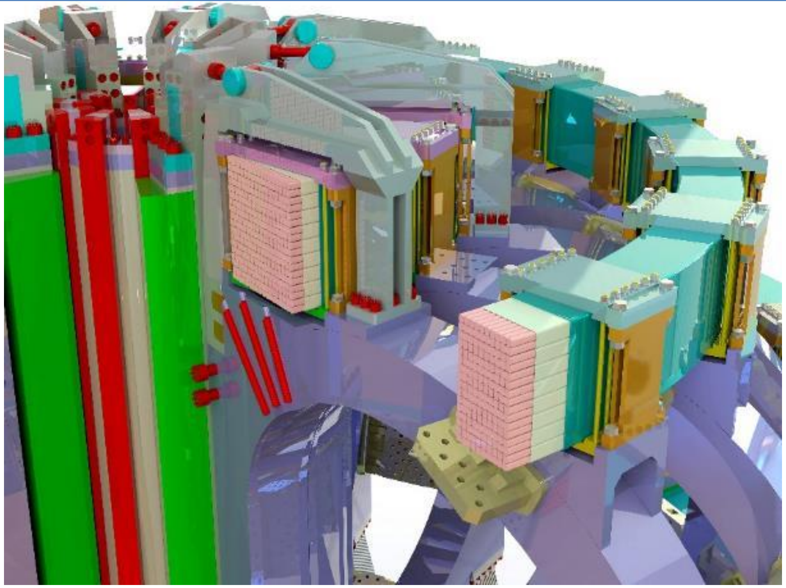
PF coils overview



	PF1/6	PF2/5	PF3/4
Iopmax [kA]	28.3	27.1	28.6
Bmax [T]	9.1	4.2	5.3
Turns (radial x vertical)	20 x 18	10 x 16	14 x 14
Dtmargin [K]	1.8	1.9	1.7
Mass [tons]	15	16	28



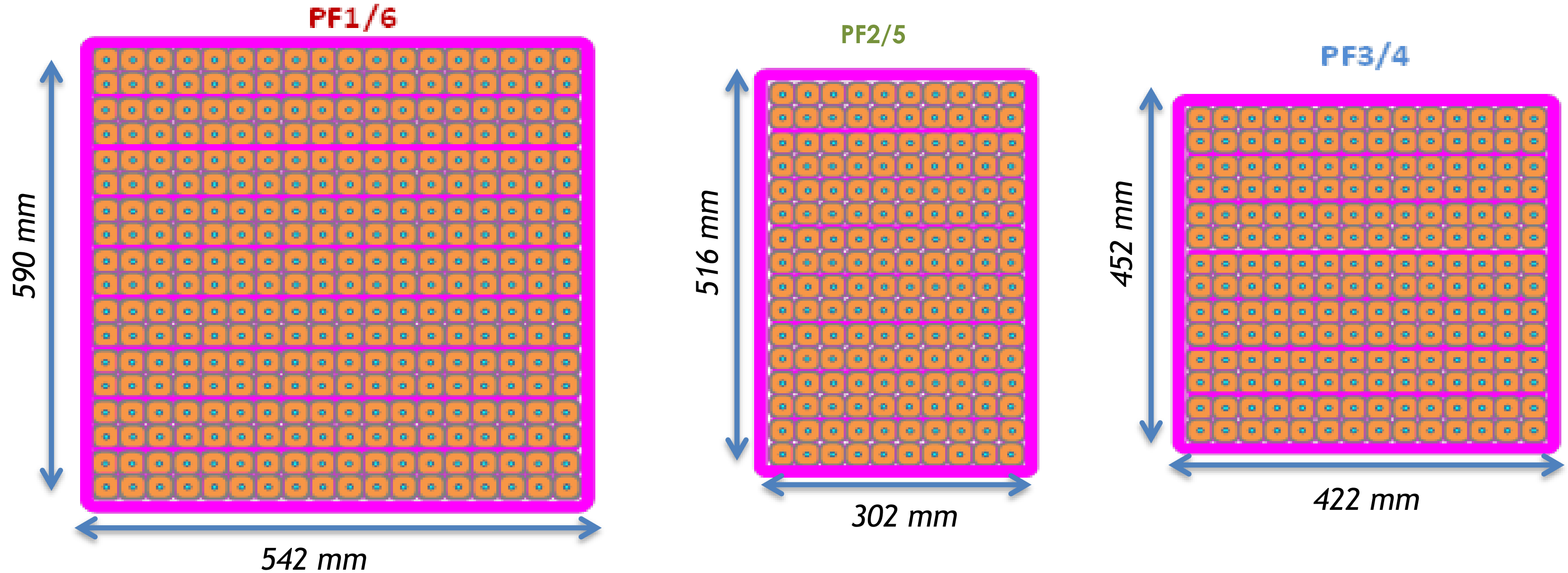
PF coils: PF winding

Most probably PF1/6 will be included in the procurement of CS

PF1/PF6:
- Coil height ~ 590 mm
- Inner diameter ~ 2,3 m
- Outer diameter ~ 3,4 m
- Mass ~ 20 tons
- Double pancakes 9

PF2/PF5:
- Coil height ~ 516 mm
- Inner diameter ~ 5,8 m
- Outer diameter ~ 6,4 m
- Mass ~ 20 tons
- Double pancakes 8

PF3/PF4:
- Coil height ~ 452 mm
- Inner diameter ~ 8,2 m
- Outer diameter ~ 9 m
- Mass ~ 33 tons
- Double pancakes 7



PF6 will be the first component to be tested and delivered

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Concluding remarks

- From 2015 to 2018 the DTT roles and objectives have been fixed and a re-baseline has been provided
- From October 2018 the integrated design activity has started
- Strands procurements has been launched in spring 2019
- Major procurements for magnets will be launched shortly in fall 2019
- Conceptual design of ancillary components based on other tokamak experiences, design to be completed within 2020
- For further info & news look at:

www.dtt-project.enea.it

www.dtt-project.enea.it/downloads/DTT_IDR_2019_WEB.pdf

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Extra slides

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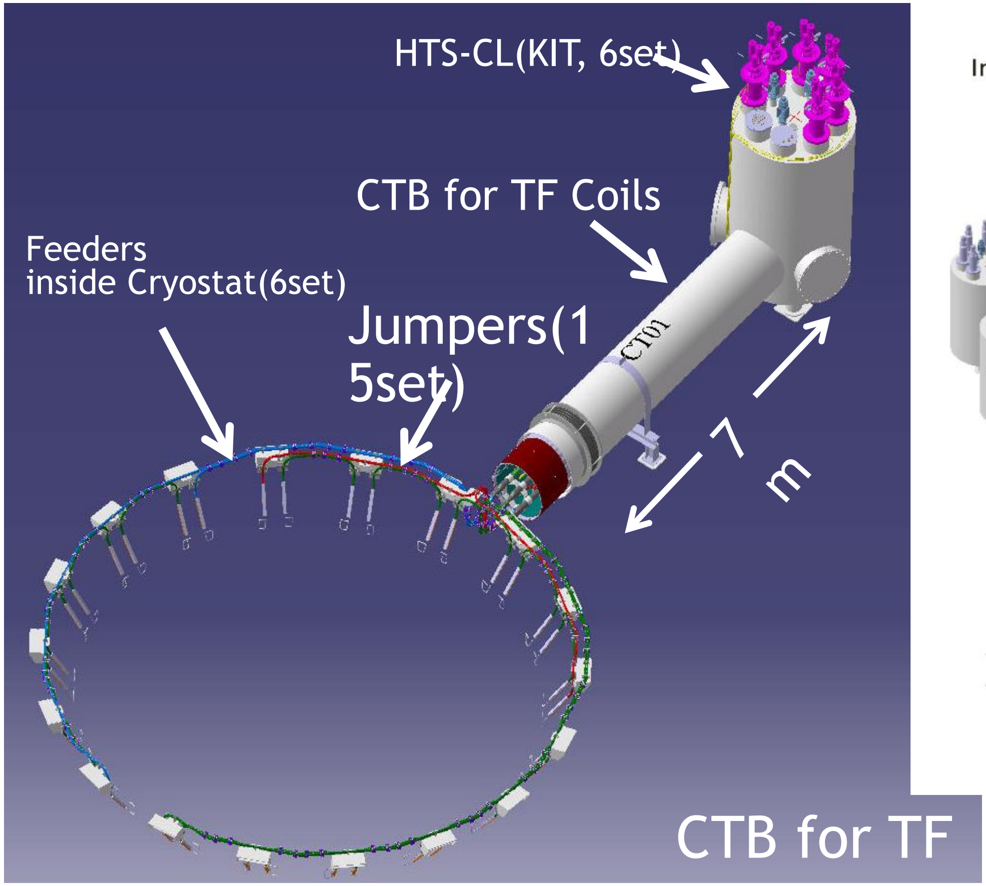
  - Feeders and current leads

Feeders and Current Leads (CL)

Feeders design completion within 2020



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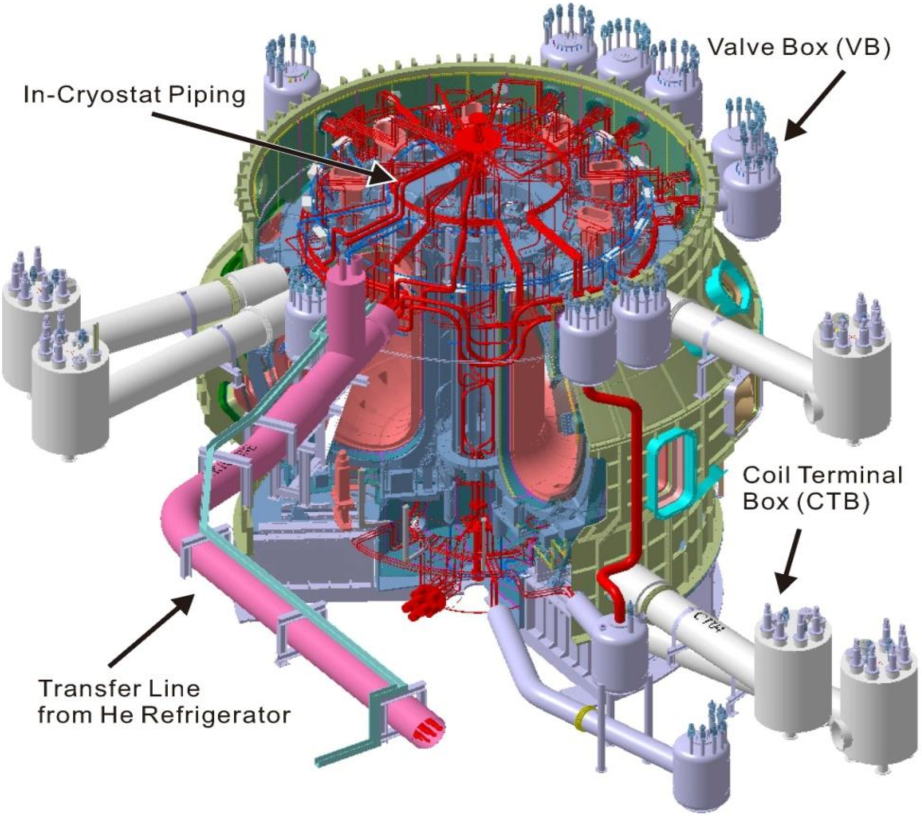

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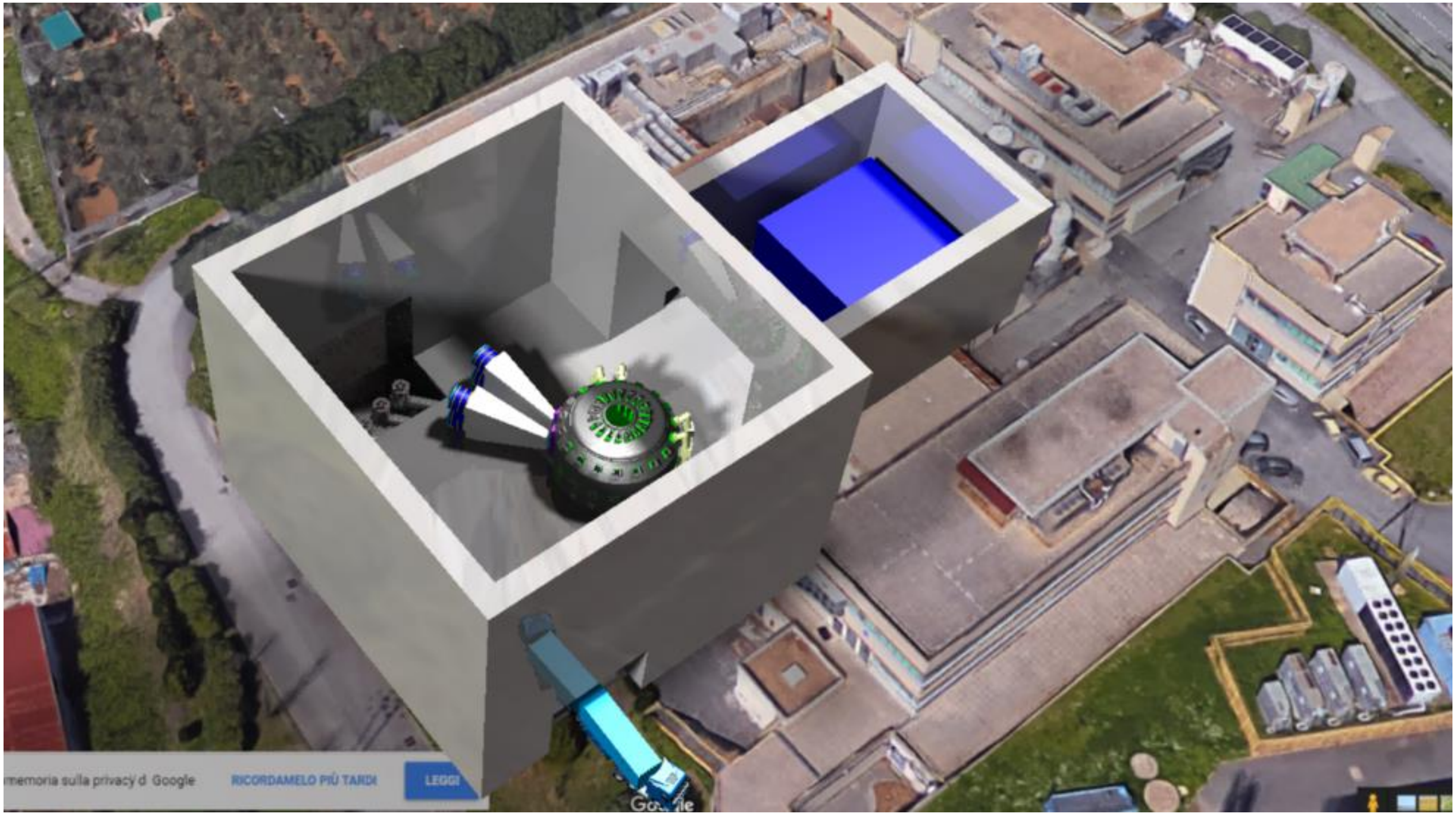
Feeders and Current Leads (CL)



6 CL for TFC in HTS
12 CL for PFC resistive
12 CL for CSC resistive

3 CL Boxes:
- PF with He dewar
- CS with He dewar
- TF

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